TECTONIC RELATIONS BETWEEN THE GALICE FORMATION AND THE CONDREY MOUNTAIN SCHIST, KLAMATH MOUNTAINS, NORTHERN CALIFORNIA

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ABSTRACT

The Upper Jurassic Galice Formation and parts of its 164 to 162 Ma Josephine ophiolite basement, both of the western Klamath terrane (WKT) have been suggested to constitute lower grade equivalents of the Condrey Mountain Schist (CMS). The high P/T CMS is exposed through a window within the Rattlesnake Creek terrane (RCT) which has been thrust westward over the WKT. The Galice-CMS correlation was based on lithologic similarities and structural position. U/Pb zircon, Ar/Ar and biostratigraphic data, however, preclude a simple stratigraphic correlation. These data may be construed as evidence for no relationships between the two assemblages with their sequential accretion as unrelated terranes. A more imaginative analysis may be constructed from the available data, however, which views the assemblages as integral parts of a rifted arc-interarc basin system which formed and subsequently closed by rapid subduction over a time interval of ~20 m.y. This model is based on a Cordilleran-scale view of the problem and on the well-documented origin of the Josephine ophiolite and its structurally underlying Rogue arc sequence as coeval interarc basin and fringing arc complexes which together formed the substrate for the Galice formation; and on a more speculative analysis of the petrogenetic setting of the CMS protolith. The age data indicate that the CMS protolith formed at ~170 Ma and earlier, and was thrust eastward beneath the RCT probably between 160 and 155 Ma. The RCT was at amphibolite grade near the thrust, and an inverted metamorphic gradient developed within the CMS. The WKT was thrust beneath the CMS and its RCT upper plate between 155 and 150 Ma. The RCT plates above and to the west of the CMS contain mafic extensional complexes of ~170 Ma (China Peak) and ≥ 164 Ma (Preston Peak) age. These complexes as well as the CMS protolith are interpreted as early manifestations of Josephine interarc basin formation. This petrogenetic and thrusting history spanned in time the Siskiyou and Nevadan regional compressional events. Within this time interval, however, major lithosphere-scale extension is indicated by the Josephine ophiolite and other extensional assemblages. This apparent contradiction in regional kinematic patterns is reconciled by recognition of important tangential displacement patterns along the Cordilleran plate edge during Jurassic time.

INTRODUCTION

The Upper Jurassic Galice Formation (Irwin, 1966, 1981; Harper and others, 1985) has been suggested to be correlative with the Condrey Mountain Schist (Hotz, 1979) exposed in a structural window to the east (Fig. 1), requiring a minimum of 110 km eastward underthrusting of Galice equivalent strata (Klein, 1977; Jachens and others, 1986). Part of the rationale for Klein's (1977) original correlation was a gross lithologic similarity between the Galice and the Condrey Mountain Schist (CMS), but observed across a strong metamorphic gradient. In fact the protolith assemblage of the CMS is more varied than the Galice, requiring the possible correlation to include mafic, ultramafic and volcaniclastic substrates of the Galice.

Distinct age differences between the Galice Formation and its substrate, and the CMS (Wells and Walker, 1953; Saleeby and others, 1982, 1984; Harper and others, 1989, in press; Helper and others, 1989; Pessagno and Blome, 1990), as well as overlap in the depositional age of the Galice and metamorphic ages of the CMS, are generally considered as evidence against their correlation and for a fundamental tectonic difference (cf. Hill, 1984, 1985; Helper, 1986). In this paper we review the age data, present new data for the CMS, and present a model for possible tectonic correlations between the two.

The western Klamath terrane (WKT) extends for ~300 km along the western margin of the Klamath Mountains geologic province (Fig. 1; Irwin, 1966; Blake and others, 1985). The Upper Jurassic Galice Formation constitutes the youngest stratified rock sequence of the WKT. The Josephine ophiolite, and nearly coeval island arc volcanic rocks of the Rogue Formation with its generally mafic metamorphic basement, constitute regionally conformable substrates for the Galice Formation in two adjacent structural blocks (Wells and Walker, 1953; Garcia, 1979, 1982; Harper, 1983). The WKT is tectonically bounded to the west by the Franciscan complex along the South Fork fault (Fig. 1). The WKT is bounded to the east by

In Dunn, G., and McDougall, K., eds.,1993,
Mesozoic Paleogeography of the Western United States-II
Pacific Section SEPM, Book 71, p. 61-80.

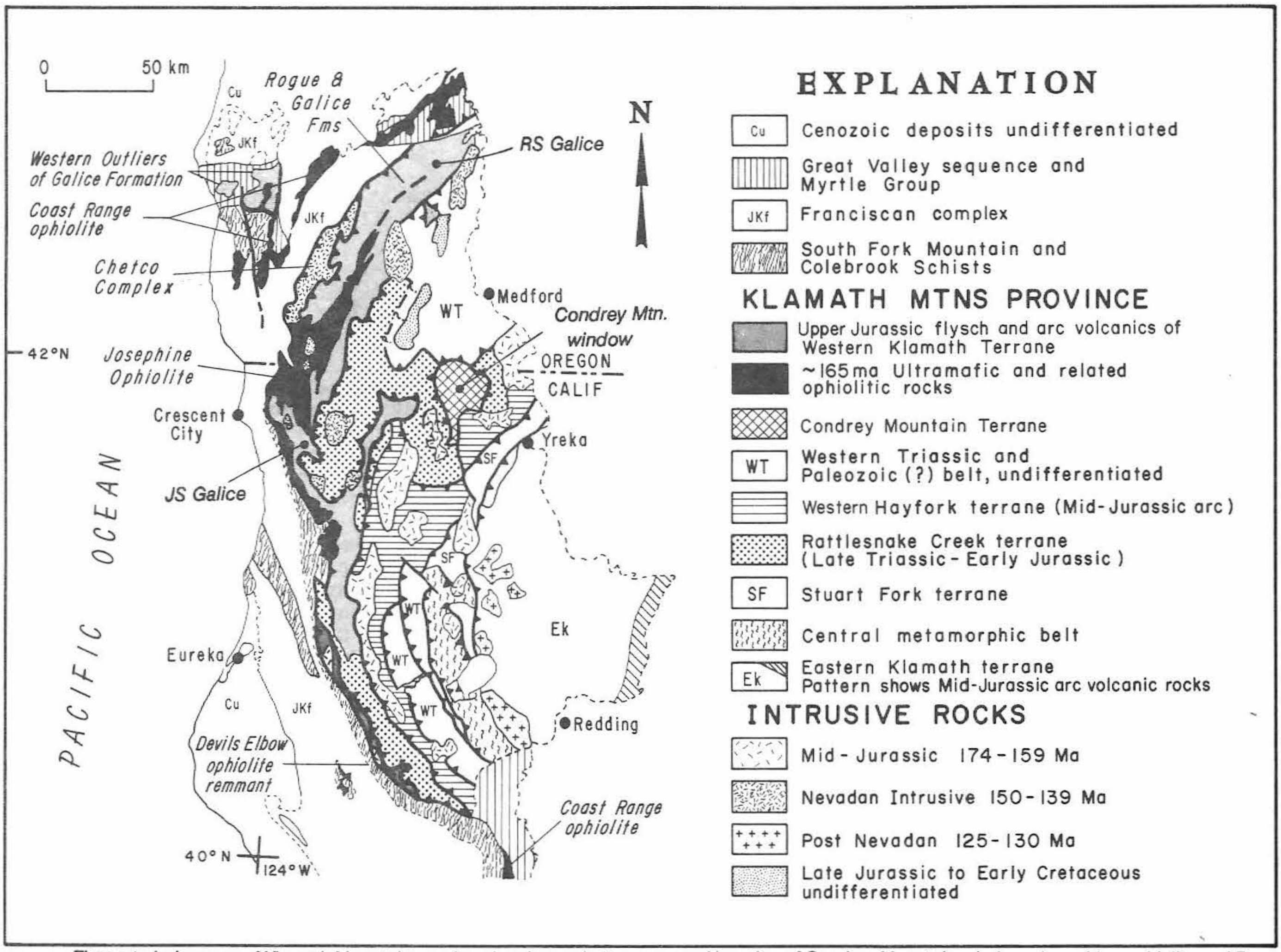


Figure 1. Index map of Klamath Mountains region showing major terranes and location of Condrey Mountain window, Josephine ophiolite and Rogue arc complex. The JS Galice corresponds to the Josephine section of Galice Formation which sits conformably above the Josephine ophiolite. The RS Galice corresponds to the Rogue section of Galice Formation which is interbedded with and above the Rogue Formation.

the Rattlesnake Creek terrane (RCT) along a regional east-dipping thrust system represented in the study area by the Orleans thrust fault (Klein, 1977; Snoke, 1977; Jachens and others, 1986).

The Condrey Mountain window is an ~30 km diameter circular fault-bounded exposure. The window formed during Neogene doming of the region and subsequent erosion (Mortimer and Coleman, 1985). A south trending appendage projects off its southwestern margin along the drainage of the Scott River (Fig. 2), which we refer informally to as the "Scott River appendage". The window exposes lower-plate CMS beneath RCT and correlative Marble Mountains terrane (MMT) rocks and tectonically transported Middle and Late Jurassic plutons (Donato and others, 1980; Saleeby and others, 1982; Barnes and others, 1986a, b; Helper, 1986). The Galice Formation and its Josephine ophiolite substrate are exposed ~50 km west of the window (Harper, 1983, 1984). There is a reentrant of WKT rocks extending eastward along the Klamath River drainage to close proximity of the window (Fig. 2; Klein, 1977). We will refer informally to this feature as the "Klamath River appendage". Recently a tectonic boundary has been hypothesized near the eastern end of this appendage separating relatively high-grade Galice phyllites from a second exposure of CMS (Fig. 2; Hill, 1984, 1985; Helper, 1986).

We will begin with a description of the major structural and stratigraphic relations of the various rock units, then focus on the geochronologic data, old and new, and then discuss alternative tectonic and paleogeographic models of the WKT including its relations with the RCT and the underlying CMS.

STRUCTURAL AND STRATIGRAPHIC FRAMEWORK

Galice Formation

The Galice Formation occurs in two main outcrop belts that are separated by regional faults, and which generally strike parallel to the regional trend of the WKT (Fig. 1). The regional structural grain is defined in both belts by generally E-dipping well-bedded turbidites and a pervasive slatey cleavage developed under prehnite-pumpellyite to greenschist facies conditions during the Late Jurassic Nevadan orogeny (Wells and others, 1949; Irwin, 1966; Coleman, 1972; Harper, 1984; Harper and others, 1988). Based on their conformably underlying substrates, the two outcrop belts are informally referred to here as: 1) the Josephine section (JS); and 2) the Rogue section (RS) which correspond to the Smith River and Rogue Valley subterranes respectively of Blake and others (1985).

The JS Galice consists of flysch (slate, metagraywacke, and rare pebble conglomerate) with a total structural thickness in excess of 4 km and a ~50 m thick basal hemipelagic sequence depositionally overlying the ophiolite. Deposition of the hemipelagic rocks in proximity to an active island arc is indicated by common presence of tuffaceous detritus, hornblende-rich tuff interbedded with the uppermost pillow lavas of the ophiolite, and the occurrence of a volcaniclastic pebbly mudstone and volcanic wackes directly overlying and interbedded with the hemipelagic srata.

Graywackes in the JS Galice are graded with partial-to-complete Bouma sequences. Deposition in very deep water is suggested by trace fossils (Harper, 1982). The graywackes have a very distinctive composition, consisting of a volcanogenic source and a source from older accreted terranes (chert-argillite and minor metamorphics; Snoke, 1977; Harper, 1983, 1984). A few chert pebbles were dated as Triassic (D.L. Jones in Harper, 1983), and detrital zircons -- some of which are clearly recycled -- are dominantly Early Proterozoic in age (Miller and Saleeby, 1987). The volcanogenic component is much less abundant up section (Harper, 1983, 1984). The graywacke provenance, as well as limited paleocurrent data (Harper, 1983; Park-Jones, 1988), suggest erosion of older terranes to the east (Snoke, 1977; Harper, 1983, 1984; Wyld and Wright, 1988).

The age of JS Galice is well constrained by fossil and radiometric ages. In the Gasquet area (Fig. 2), the underlying Josephine ophiolite has yielded a 162 ±1 Ma U/Pb age and a 165 ±3 Ma $^{40}Ar/^{39}Ar$ hornblende age, and the Galice is intruded by dikes, sills, and plutons as old as 150 ±1 Ma (Harper and others, in press). The stratigraphic age of the ophiolite is late Callovian based on radiolaria collected from rare mudstones interbedded with pillow lavas (Pessagno and Blome, 1990). The hemipelagic sequence spans the Oxfordian according to Pessagno and Blome (1990), and the basal flysch contains Buchia concentrica of middle Oxfordian to upper Kimmeridgian age.

The Josephine ophiolite is an aerially large and complete ophiolite section which forms depositional basement for the JS Galice (Fig. 2; Harper, 1983, 1984). The pillow lavas and dikes have island-arc tholeiite affinities (Harper, 1984, 1989; Wyld and Wright, 1988). An additional small remnant of the Josephine ophiolite in the Devils Elbow area of the southern Klamath Mountains (Wyld and Wright, 1988) has yielded a 164 ±1 Ma U/Pb zircon age (Wright and Wyld, 1986) and is depositionally overlain by Galice Formation with similar stratigraphic relations to those discussed above (Fig. 3). Importantly, the plagiogranites at this location contain Proterozoic xenocrystic zircon suggesting that this part of the ophiolite is intruded through older Klamath basement and thus represents a rift facies of the Josephine basin that included older crust (Wyld and Wright, 1988).

The Josephine ophiolite contains large lenses of probable RCT rocks along generally N-trending narrow belts (Harper and others, 1985; Wyld and Wright, 1988; Harper, 1989). These belts of older crustal assemblages lie at high angles to the strike of sheeted dikes. They are interpreted as fragments of RCT-like basement that were dislodged by boundary transform faulting and encased within the Josephine juvenile lithosphere during north-south directed spreading (Wyld and Wright, 1988).

The RS Galice is lithologically identical to the JS Galice, is of similar age, and contains similar traces of craton-derived detrital zircon (Wells and Walker, 1953; Harper, 1984; Miller and Saleeby, 1987; Pessagno and Blome, 1990). Structural thickness is locally in excess of 2 km; it interfingers with and lies conformably above the Rogue Formation, a >3 km-thick Oxfordian and possibly older submarine volcanic flow and pyroclastic sequence built within an oceanic island arc setting (Wells and Walker, 1953; Garcia, 1979, 1982; Saleeby, 1984; Riley, 1987; Park-Jones, 1988). Apparent basement for the Rogue Formation consists of mafic amphibolite, Middle Jurassic dioritic to ultramafic intrusive rocks, and serpentinized peridotite referred to as the Briggs Creek subterrane (Blake and others, 1985). This subterrane hosts the Middle(?) to Late Jurassic Chetco batholithic complex interpreted by Dick (1976), Garcia (1979, 1982) and Harper and Wright (1984) as the plutonic roots for the Rogue arc. The Briggs Creek subterrane may represent a large rifted fragment of RCT-like rocks dislodged in a fashion similar to the smaller lenses within the Josephine ophiolite (Yule and others, 1992). The Rogue arc sequence appears to have nucleated on this basement fragment.

The JS Galice and Josephine ophiolite were thrust eastward beneath the RCT during the Late Jurassic Nevadan orogeny (Snoke, 1977; Saleeby and others, 1982; Harper and Wright, 1984; Jachens and others, 1986). The Klamath River appendage of JS Galice indicates >40 km of westward movement along the Orleans thrust, and geophysical data suggests >110 km. Movement on this thrust occurred at ~155 to 150 Ma based on the age of the JS Galice and the 150±1 Ma Summit Valley and 148±1 Ma Pony Peak plutons which cut the thrust (Harper and others, in press). As a result of underthrusting, the JS Galice was metamorphosed to low grade, and penetratively deformed (Harper, 1984, 1989).

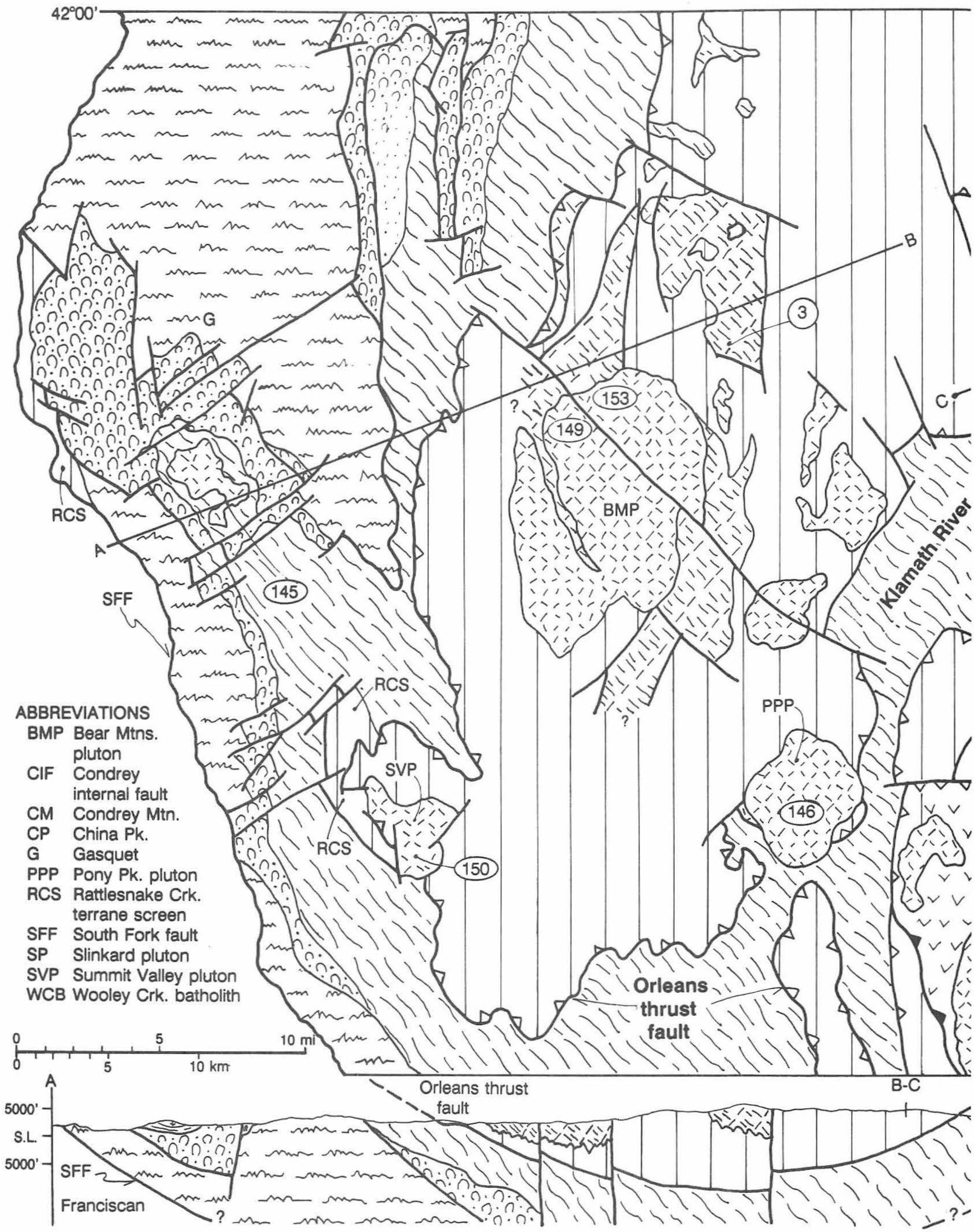
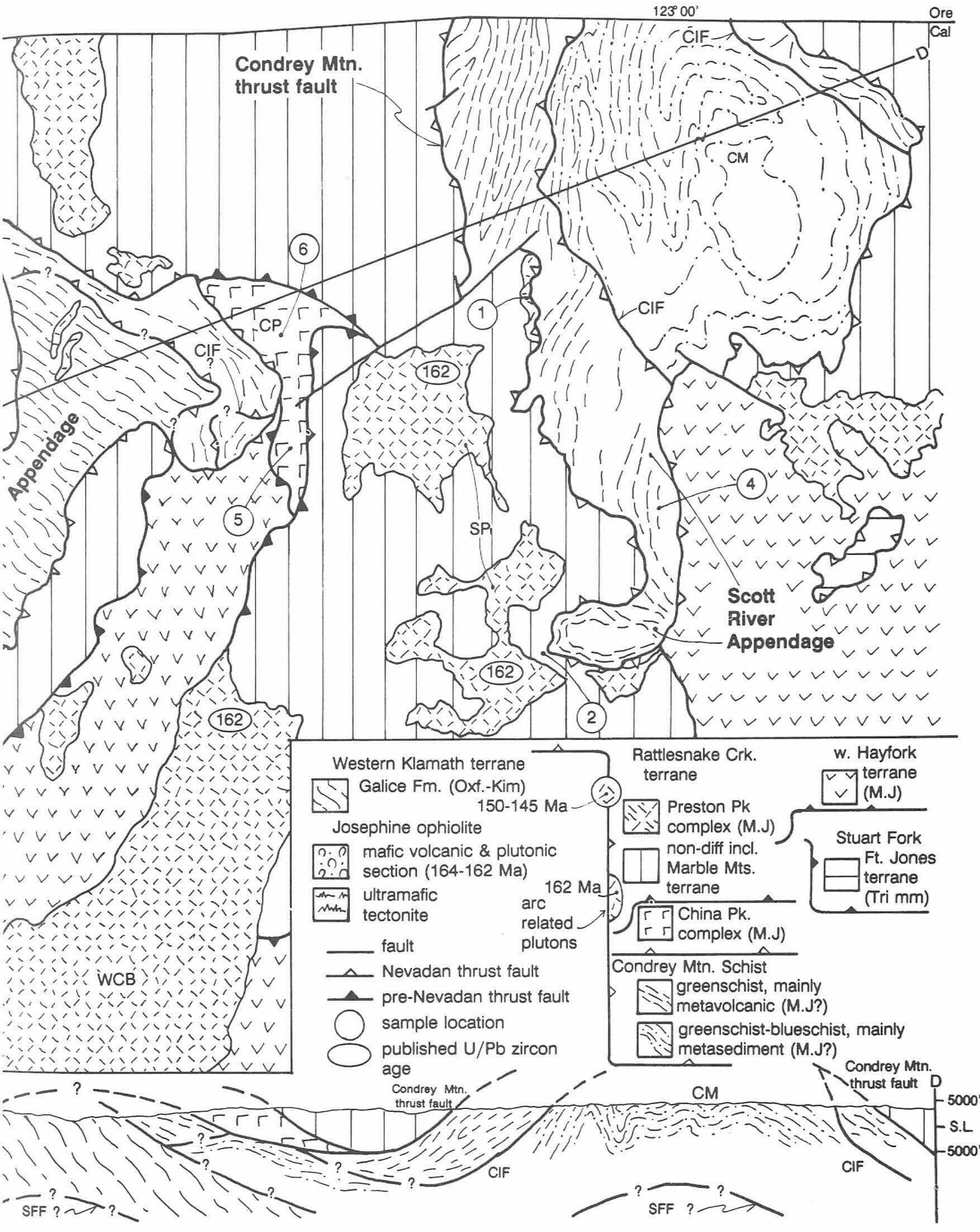


Figure 2. Generalized geologic map and cross section of the west-central Klamath Mountains region between the western Klamath terrane and the region of the Condrey Mountain window. Location of U/Pb zircon and Ar/Ar age samples is also shown as well as published U/Pb zircon dates



on key cross-cutting intrusions. Geology after Klein (1977), Donato and others (1980), Saleeby and others (1982), Harper (1984), Hill (1984, 1985), Helper (1986), Jachens and others (1986), Wagner and Saucedo (1987).

In a number of locations the JS Galice exhibits an asymmetric NW-verging multiple thrust packet geometry with broken formation disruption of fold limbs, suggesting an accretionary prism-type of deformation. SE-directed underthrusting at a low angle to slatey cleavage is evident from numerous small slickenfiber-coated faults (Harper, 1992), many of which offset the calc-alkaline dikes of ~150 Ma age. Early ENE-directed underthrusting, however, is suggested by small faults that predate cleavage and which are commonly intruded by the ~150 Ma dikes (Harper, 1992).

In the Klamath River appendage, the lithology and structure of the JS Galice is very similar to that in the west (Gray, 1985), although the metamorphism is lower greenschist facies rather than prehnite-pumpellyite facies (Harper and others, 1988). Metamorphism in the Galice appears to increase significantly as the thrust contact with the CMS is approached (Klein, 1977).

The Josephine ophiolite was thrust NNE (present coordinates) over the RS Galice and its Chetco batholithic root during Late Jurassic Nevadan orogeny (Dick, 1976; Grady, 1990; Harper and others, 1990). It is likely that all inferred thrusting directions need to be corrected for post-Nevadan vertical-axis rotation (e.g., Renne and Scott, 1988; Mankinen and Irwin, 1991). Because insufficient paleomagnetic data is available for the study area, structural data will be corrected for clockwise rotations by assuming the arcuate shape of the WKT is oroclinal. Oroclinal bending is strongly supported by the paleomagnetic data of Renne and Scott (1988) to the southeast of the study area which show that the amount of rotation correlates with structural trends. Structural data for the WKT are thus corrected by a counter-clockwise rotation in an amount needed to bring the regional structural trend into parallelism with those in the Sierra Nevada (N40W) where there has been little post-Nevadan rotation (e.g., Bogen and others, 1985; Frei, 1986). This method would indicate that the northern part of the WKT has rotated ~65° clockwise, with poorly constructed paleomagnetic studies suggesting 78 ±26°, 99 ±10°, and 113 ±16° of clockwise rotation (Schultz, 1983; Bogen, 1986). Assuming oroclinal bending, the overthrusting direction of the Josephine ophiolite rotates to a NW trajectory, and underthrusting of the JS Galice rotates to early NNE and later E trajectories. We will refer to these thrust kinematic trajectories in our tectonic discussions.

In summary, the Galice Formation is a flysch sequence which overlapped contrasting basement terranes consisting of juvenile oceanic crust of the Josephine ophiolite, and an adjacent polygenetic oceanic basement fragment derived from RCT-like rocks and the overlying Rogue island arc sequence. During the Nevadan orogeny, the Galice Formation and its varied substrate were internally imbricated and thrust eastward beneath the RCT and at deeper structural levels to the east beneath the CMS.

Condrey Mountain Schist

The CMS may be divided into two lithologic assemblages separated by an internal fault that may have originally been pre- or syn-metamorphism (Fig. 2; Donato and others, 1982; Helper, 1986; Coleman and others, 1988), but may also have undergone late-stage normal reactivation. We will refer to this structure as the "internal fault". The structurally higher assemblage is exposed along the western margin of the window and consists of mafic schist with subordinate silicic and graphitic quartz-mica schist and diorite gneiss, all metamorphosed to greenschist facies. A thin selvage of the upper assemblage runs along the northeast margin of the schist, suggesting that the upper assemblage was a thin plate constituting the upper levels of much or all of the schist and that the internal fault has been domed with the window. The lower assemblage constitutes the core and much of the eastern margin of the window and consists of graphitic and quartz-mica schist, metachert, mafic schist and subordinate metaperidotite, all metamorphosed to transitional greenschist-blueschist facies. Igneous and metamorphic geochronologic data discussed below indicate an ~170 Ma or older protolith age for the schist and commencement of metamorphism possibly as early as ~160 Ma. The CMS protolith is thus older than the Galice Formation.

The protolith history of the CMS records deep basinal and, at least locally, turbiditic sedimentation and influx of intermediate to silicic volcaniclastic material with mafic-ultramafic ophiolitic and/or oceanic arc basement rocks. The overall association is not unlike the Galice Formation and its variable substrates, or alternatively parts of the western Hayfork terrane, discussed below.

The gross structure of the CMS is a broad dome that warps a generally flat lying transposition foliation that is sub-parallel to the internal fault and to the circumscribed (Condrey) thrust contact with the overlying RCT and MMT (Donato and others, 1980; Coleman and others, 1983; Helper, 1986). The regional transposition foliation contains a NNE-SSW shallow plunging stretching lineation and exhibits multiple phases of synmetamorphic folding with early NW-SE striking NE dipping axial surfaces and later steep NE striking axial surfaces; horizontal flattening and boudinage was progressive throughout this deformation sequence (Hill, 1984, 1985; Helper, 1986; Brown and Blake, 1987). Along the western sector of the Condrey thrust, the stretching lineations are re-oriented to an E-W trend. These main phases of deformation were followed by E-W trending kink bands, chevron and box folds and finally late-stage regional doming (Helper, 1986; Mortimer and Coleman, 1985). The effect of oroclinal bending on the CMS is unknown. We assume a similar sense of rotation as that discussed for the Galice Formation, but perhaps of lower magnitude considering the location of the window closer to the center of the Klamath Mountains.

Little work has been done on the Condrey Mountain thrust fault. At a number of locations, it has been modified by high-angle normal(?) faulting, particularly along the eastern margin of the Scott River appendage. Critical thrust relations are well-exposed along the southern end of the appendage where lower plate greenschist facies metabasite appears to increase to epidote amphibolite and garnet amphibolite grade rock as the thrust is approached (Barrows, 1969; Welsh, 1982). In the thrust zone coarse-grained garnet amphibolite mafic gneiss contains trondjemitic leucosomes and intrusive pods (Welsch, 1982; Coleman and others, 1988). The upper plate rocks here cannot be easily distinguished from high-grade lower plate mafic schist. Indeed, Barrows (1969) considered the upper plate mafic gneisses as high-grade lower plate rock. The southern end of the Scott River appendage records an inverted metamorphic gradient with comparable garnet amphibolite grade rocks in both the upper and lower plates along the thrust, passing downward into lower plate epidote amphibolite, greenschist, and ultimately continuing northward transitional greenschist-blueschist facies rocks. Remnants of a similar metamorphic gradient appear to be preserved elsewhere along the Condrey thrust, where not modified by high-angle faulting.

A second tectonic inlier of CMS mainly mafic in composition is hypothesized to occur ~20 km west of the Condrey Mountain window at the eastern terminus of the Klamath River appendage (Hill, 1984, 1985; Donato, 1987; Coleman and others, 1988). Klein (1975, 1977) considered these rocks as part of an inverted metamorphic gradient through the Galice Formation. Hill (1984, 1985) considers these rocks as three distinct thrust bounded terranes with lowest structural level Galice, the highest structural level an amphibolite-grade mafic dike complex belonging to the RCT, and the intervening greenschist grade metabasite and carbonaceous pelite belonging to the CMS. The rocks of this structural sequence all show high synmetamorphic strain with west-directed ductile thrust displacement accompanied by penetrative flow. Thrust faults and questionable thrust faults (Fig. 2) are delineated primarily by zones of steep metamorphic gradient with only subtle protolith change. The structural-metamorphic relations of the eastern Klamath River appendage are critical, as are those of the southern Scott River appendage; these will be discussed further below.

The Orleans thrust fault extends up the Klamath River appendage between upper plate RCT and MMT rocks and lower plate Galice slate and phyllite, and the western exposure of CMS. Gravity analysis suggests that the Orleans thrust re-emerges to the east as the Condrey Mountain thrust (Jachens and others, 1986), which is one of the main reasons for our re-analysis of the Galice CMS correlation problem.

Rattlesnake Creek Terrane (RCT)

Rocks correlated with the RCT within the study area are referred to as the Marble Mountains terrane (MMT; Donato, 1987; Coleman and others, 1988), distinguished as being the structurally lowest and generally highest metamorphic grade equivalent of the RCT. We will focus primarily on rocks that lie west of the Condrey Mountain window, including those lying between the Klamath River appendage and the Josephine ophiolite; these are most pertinent to the Galice-CMS problem. They consist primarily of ophiolitic melange with blocks of metaperidotite and metaserpentinite, mafic gneiss, quartz-biotite schist, and marble, much of which was metamorphosed en masse under amphibolite facies conditions (Donato and others, 1980, 1982; Hill, 1984, 1985; Donato, 1987; Coleman and others, 1988). Protolith ages are poorly constrained, although correlative lower grade ophiolitic melange to the south (Gray and Peterson, 1982; Rawson and Peterson, 1982) yields 193 to 207 Ma U/Pb zircon igneous ages and Late Triassic and Early or Middle Jurassic fossil ages (Wright, 1981; Irwin and others, 1982; Wright and Fahan, 1988).

Two distinctly younger mafic complexes occur within the RCT of the study area. To the west and at high structural levels occurs the static greenschist grade Preston Peak mafic complex which was constructed across pre-existing ophiolitic melange in Middle Jurassic time (Fig. 2; Snoke, 1977; Saleeby and others, 1982; Yule and others, 1992). At deeper structural levels in the China Peak area is a ductile-thrust bounded amphibolite-grade mafic sheeted dike complex with subordinate layers of mafic metavolcanic and siliceous metasedimentary rock. These rocks are referred to by us informally as the China Peak complex which also formed in Middle Jurassic time. Analogous Middle Jurassic mafic igneous complexes have not yet been recognized in the lower grade RCT to the south. We raise the possibility below that the China Peak complex is separate from and structurally beneath the RCT.

The RCT of the study area records multiple phases of thrusting and at least one penetrative ductile deformation and mainly amphibolite facies metamorphic event, all superimposed over the ophiolitic melange structure (Snoke, 1977; Donato and others, 1980, 1982; Hill, 1984, 1985; Donato, 1987; Coleman and others, 1988). The main event is termed the "Siskiyou" (Coleman and others, 1988), and consisted of low P/T dynamothermal metamorphism during west-directed thrusting between ~170 and 162 Ma (Harper and Wright, 1984; Barnes and others, 1986a; Coleman and others, 1988; Wright and Fahan, 1988). The Wooley Creek batholith and Slinkard plutons (Fig. 2) crosscut Siskiyou structures at 162 Ma, but are themselves rootless and have been transported with their RCT host above the CMS by post-Siskiyou thrusting (Barnes and others, 1986a, b). Adjacent to the Condrey Mountain window, only the late-metamorphic folds with NE striking axial surfaces, the post-metamorphic E-W trending kinks and folds, and the later doming affect both lower and upper plate rocks (Hill, 1984, 1985).

The RCT is regionally overlain with low-angle tectonized contacts by the western Hayfork terrane (WHT; Charlton, 1978; Wright, 1981; Hill, 1984, 1985; Donato, 1987; Wright and Fahan, 1988). The WHT is a generally intact sequence of Middle Jurassic volcaniclastic strata (Wright and Fahan, 1988). The volcaniclastic strata consists of submarine coarse flow breccias, turbidites and finely layered tuff of mainly basalt to andesite composition. It is a submarine island arc sequence, in many aspects similar to the Rogue Formation, but distinctly older. The upper stratigraphic levels of the WHT contain significant proportions of epiclastic and hemipelagic material suggesting a decrease in volcanism during the influx of epiclastic material derived from continental or uplifted accretionary terranes to the east (Wright and Fahan, 1988).

A number of relations suggest that the WHT was originally deposited above the RCT, and perhaps other Klamath terranes to the east. Possible depositional contacts have been noted by Charlton (1978) and Donato (1987). Eruptive ages based on K/Ar data on fresh phenocrystic hornblende overlap the spread of concordant U/Pb zircon ages on a regionally extensive suite of peridotitic to dioritic intrusions which cut the RCT as well as other Klamath terranes to the east, and are interpreted as the plutonic roots of the WHT volcaniclastic rocks (Wright and Fahan, 1988). Western Hayfork volcanic ages are as old as 177 Ma, and low-angle imbrication with the RCT was completed by 162 Ma as part of the Siskiyou event. It should be noted that in most localities the low-angle contacts place younger lower grade WHT rocks above older higher grade, presumed basement rocks, of the RCT. This raises the possibility that some of the low-angle contacts could be, or could have originally been, normal faults (Saleeby, 1990, 1992). Small tectonic outliers of Stuart Fork-Fort Jones terrane rocks lie above RCT rocks in the southeastern part of Figure 2. This higher structural level terrane constitutes a Triassic high P/T metamorphic assemblage that was partly exhumed in Early Jurassic time and then thrust westward over the RCT in Siskiyou time (Davis and others, 1978; Wright and Fahan, 1988; Saleeby and Busby-Spera, 1992).

GEOCHRONOLOGIC DATA

An extensive body of U/Pb zircon and K/Ar-Ar/Ar geochronologic data exists for plutonic and metamorphic rocks of the study area (Lanphere and others, 1968; Saleeby and others, 1982; Welsch, 1982; Barnes and others, 1986a; Helper and others, 1989; Coleman and others, 1988; Donato and Lanphere, 1992; Harper and others, in press). Figure 2 shows the most important data plotted on the geologic base, including new data presented in this paper. Below we present new U/Pb zircon and $^{40}Ar/^{39}Ar$ data on key rocks of the Condrey Mountain window and the upper plate RCT. In presenting the data, we will elucidate the important geologic features of the samples and then integrate the data into a discussion of previous data and its tectonic implications. The U/Pb zircon data is presented in Table 1. Analytical procedures are identical to those used in Harper and others (in press). The results of the U/Pb zircon data are summarized in a series of stacked segments of concordia in Figure 3 (after Tera and Wasserburg, 1972). The $^{40}Ar/^{39}Ar$ data are presented as Ar release spectra and isochron plots in Figure 4.

New Data

Condrey Mountain Schist

Protolith age constraints for the CMS are meager and have for the most part been provided by metamorphic cooling ages and structural relations. The upper mafic greenschist contains a 100m-scale gneissic metadiorite that contains all structural and metamorphic features of its host. Samples 4a and 4b were taken from adjacent exposures of the gneiss. Three zircon fractions from the two samples are externally concordant at 170±1 Ma (Fig. 3). The mafic schist host is thus at least 170 Ma old, and deformation and metamorphism of the CMS occurred post-170 Ma.

Additional U/Pb zircon ages for the schist protolith were reported in Helper and others (1989); a 172±2 Ma age was reported for our sample 4 metadiorite, and a 170±1 Ma age was reported for a felsic metavolcanic schist from the lower greenschist-blueschist assemblage. An eruptive versus depositional origin of the metavolcanic schist is not clear due to metamorphism-deformation, which poses the possibility of its having been reworked. Nevertheless, we consider the 170 Ma age to be a reasonable protolith constraint for at least part of the lower assemblage.

Rocks Immediately Above the Condrey Mountain Thrust

Garnet amphibolite grade mafic gneisses at the southern end of the Scott River appendage represent rocks of the Condrey thrust fault, and/or proximal upper plate rocks. Hornblende (sample 2a) from the mafic gneiss yields a $^{40}Ar/^{39}Ar$ release spectra that is dominated by two steps in which nearly all the ^{39}Ar was released with a plateau age of 152 ±1 Ma (Fig. 4). This age records the time of hornblende closure at ~450°C and should approximate the end of amphibolite facies metamorphism and deformation associated with the Condrey thrust fault. A very similar $^{40}Ar/^{39}Ar$ age was reported by Donato and others (1992) from the same location.

The gneissic amphibolite of sample 2a contains syntectonic trondjemite leucosomes

TABLE 1. ZIRCON ISOTOPIC AGE DATA

			Concentrations (ppm)			Atomic ratios			Isotopic ages (Ma) §		
Sample	Fraction † (μm)	Amount analyzed (mg)	^{238}U	$^{206}Pb^*$	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{206}Pb^*}{^{238}U}$	$\frac{^{207}Pb^*}{^{235}U}$	$\frac{^{207}Pb^*}{^{206}Pb^*}$	$\frac{^{206}Pb^*}{^{238}U}$	$\frac{^{207}Pb^*}{^{235}U}$	$\frac{^{207}Pb^*}{^{206}Pb^*}$
Scott River granophyre (41°40.9'N 123°05.9'W)											
2b	<45	1.2	555	12.1	3670	0.02515(18)	0.1711	0.04938(08)	160	160	166 ± 4
	45 - 62	0.5	394	8.4	4407	0.02478(15)	0.1682	0.04926(08)	157	157	159 ± 4
Preston Peak complex felsic dike (41°50.7'N 123°36.7'W)											
3	80 - 100a	1.1	325	7.3	3375	0.02583(14)	0.1757	0.04935(09)	164	164	164 ± 4
Condrey Mountain Schist sill (41°45.7'N 123°03.8'W)											
4a	<80	13.5	138	3.2	236	0.02673(27)	0.1832	0.04965(25)	170	172	179 ± 10
4b	<45	5.1	409	9.4	4161	0.02662(21)	0.1811	0.04948(10)	169	169	170 ± 6
	45 - 80	10.1	199	4.6	2168	0.02693(22)	0.1837	0.04950(12)	171	171	171 ± 6
China Peak complex felsic dike (41°46.9'N 123°15.05'W)											
5	<45	3.2	399	9.3	1501	0.02697(24)	0.1847	0.04966(15)	172	172	179 ± 8
	45 - 80	0.8	248	5.8	211	0.02718(28)	0.1856	0.04956(40)	173	173	174 ± 18
China Peak complex felsic dike (41°50.0'N 123°15.7'W)											
6	<45	0.3	144	3.31	6542	0.02664(14)	0.1816	0.04947(08)	169.5	169.5	170 ± 4

* Radiogenic; nonradiogenic correction based on 25 picogram blank Pb (1:18.78:15.61:38.50) and initial Pb approximations: 1:18.6:15.6:38.8 (Stacy and Kramer, 1975)

† Fractions separated by grain size and magnetic properties. Magnetic properties are given as non-magnetic split at side/front slopes for 1.7 amps on Franz Isodynamic Separator. Samples hand-picked to 99.9% purity prior to dissolution; a = grains abraded by technique similar to Krogh (1982). Dissolution and chemical extraction techniques modified from Krogh (1973).

§ Decay constants used in age calculations: $\lambda^{238}U = 1.55125 \times 10^{-10}$, $\lambda^{235}U = 9.8485 \times 10^{-10}$ (Jaffey and others, 1971); $^{238}U/^{235}U$ atom = 137.88. Uncertainties in $^{206}Pb^*/^{238}U$ and $^{207}Pb^*/^{206}Pb^*$ are given as "±" in last two figures. Uncertainties calculated by quadratic sum of total derivatives of ^{238}U and $^{206}Pb^*$ concentration and $^{207}Pb^*/^{206}Pb^*$ equations with error differentials defined as 1. isotopic ratio determinations from standard errors ($\sigma/\sqrt{n}$) of mass spectrometer runs plus uncertainties in fractionation corrections based on multiple runs of NBS 981, 982, 983, and U500 standards; 2. spike concentrations from range of deviations in multiple calibrations with normal solutions; 3. spike compositions from external precisions of multiple isotope ratio determinations; 4. uncertainty in natural $^{238}U/^{235}U$ from Chen and Wasserburg (1981); and 5. nonradiogenic Pb isotopic

and intrusive pods that may represent local anatectic melts developed during the thermal and deformation peak of thrust faulting. Local small degrees of partial melting may have been promoted by upward flux of water-rich fluids driven off the prograde reactions within the lower plate CMS (Welsh, 1982). Sample 2b is from a granophyric domain within one of the larger pods. A very large sample (~100 kg) yielded only ~2 mg of fine heterogeneous zircon. The finer fraction showed greatest heterogeneity and yielded slightly discordant ages plotting just above 160 Ma on concordia (Fig. 3). The coarser fraction was more homogeneous, clearer and euhedral and yielded 157±1 Ma concordant ages. The external discordance between fractions may reflect small amounts of recycled zircon in the finer heterogeneous fraction, and/or small amounts of open system behavior in the coarser fraction. Taking these both into account our interpreted age for the granophyre is 157+3/-2 Ma. This approximates the time of peak metamorphism along the thrust. Earlier (160 to 170 Ma) igneous generation followed by open system behavior of the zircon is possible providing metamorphism and possible local anatexis commenced during the Siskiyou event, and that progressive metamorphism extended into post-Siskiyou time along the thrust.

A small diorite body in the upper plate is cut by the Condrey thrust along the western margin of the window (Helper, 1986; Wagner and Saucedo, 1987). The igneous age of the intrusion is unknown, although it is probably related to the nearby 162 Ma Slinkard pluton which is immediately above the Scott River appendage (Barnes and others, 1986a). Helper (1986) reported a K/Ar hornblende age of 156 ±3 Ma for the diorite. We analyzed a split of Helper's hornblende and obtained a well-defined plateau with a corresponding isochron age of 156.2 ±0.7 Ma (Sample 1, Fig. 4). The initial steps yielded young ages with corresponding high K/Ca ratios, indicating minor loss of radiogenic Ar at ~110-120 Ma, probably from an exolved amphibole phase having a low

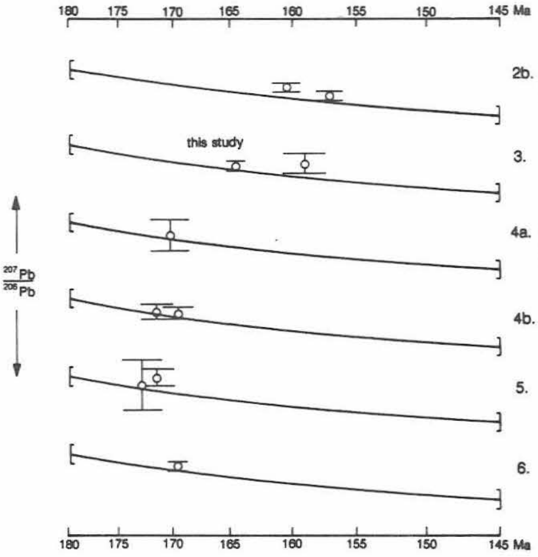


Figure 3. Stacked segments of $^{238}U/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ concordia diagrams (after Tera and Wasserburg, 1972) showing relations of concordant to slightly disconcordant data points with concordia. Bars at end of concordia lines are uncertainties in position of concordia based on uncertainties in decay constants (after Mattinson, 1987).

closure temperature (Harrison and Fitz Gerald, 1986). The 156 Ma isochron age records closure at ~500°C.

The amphibolite-grade China Peak complex occurs as a thrust plate between the CMS exposure at the eastern end of the Klamath River appendage, and higher level RCT and WHT rocks (Fig. 2; Hill, 1984, 1985). Samples 5 and 6 are from small presumed cogenetic metaplagiogranite layers in sheeted dikes. Sample 5 yielded two factions that are externally concordant at 172 ±1 Ma, and sample 6 yielded a meager fine euhedral population that is internally concordant at 170 ±1 Ma (Fig. 3). These are interpreted as the igneous age of the dike complex.

The 172 Ma age for the sheeted dike complex is atypical for ages of the ophiolite components present throughout much of the RCT (Wright, 1981, 1982). One possible analogue for this relatively young component is the Preston Peak mafic complex exposed ~25 km to the west at the highest structural levels of the RCT in the study area (Snoke, 1977; Saleeby and others, 1982). This complex consists of diabasic intrusives and overlying scree breccia, mafic lavas and silicious argillite that were built across older ophiolitic melange and ultramafic tectonite. Snoke and others (1977) reported a late-stage leuco-quartz diorite dike that is internal to the complex and thought to be genetically related to the diabases. Saleeby and others (1982) reported a slightly discordant U/Pb zircon age suggesting a ~160 Ma age. We have re-analyzed the small amount of residual zircon from the original sample, but have subjected it to air abrasion (after Krogh, 1982) in order to remove outer grain domains which may be more susceptible to open system behavior. The resultant analysis yields a drop in U concentration from 422 to 325 ppm and a shift to internal concordance at 164 ±1 Ma (Fig. 3).

The 164±1 Ma age for the Preston Peak leuco-quartz diorite is interpreted as the approximate or near-minimum age of the mafic complex. In the strict sense the zircon age can only be interpreted as a minimum age for the complex; other factors suggest the broader reaching interpretation, however. First, the Preston Peak mafic complex does not show the affects of dynamothermal metamorphism that is typical of the Siskiyou event. The static-textured low-grade hypabyssal part of the complex actually crosscuts metamorphic tectonite fabrics that are typical of Siskiyou metamorphism and deformation (Snoke, 1977; Saleeby and others, 1982). Furthermore, the arc-related Bear Mountains intrusion that crosscuts the Preston Peak complex is 153 to 150 Ma in age (Saleeby and others, 1982), in contrast to the ~162 Ma age of the arc-related Wooley Creek batholith and Slinkard pluton to the east (Barnes and others, 1986); this is not inconsistent with the ~164 Ma age for the Preston Peak mafic complex. Recent detailed examination of the Preston Peak mafic complex and similar rocks of the Illinois River area to the north lead to the conclusion that substantial extensional brecciation, faulting and low-grade static metamorphism accompanied igneous construction (Yule and Saleeby, 1991; Yule and others, 1992). Whether or not this extensional tectonic domain occurred in conjunction with extension recorded by the 170 to 172 Ma China Peak complex is unknown.

Geochronologic Overview

Thrusting and Metamorphism of the Condrey Mountain Schist

The timing of metamorphism for the CMS is constrained by a number of different geochronologic and geologic relations. The U/Pb zircon ages on the sample 4 metadiorite and on the felsic metavolcanic units (Helper and others, 1989) indicates that metamorphism and deformation began later than 170 Ma. Coleman and others (1988) interpret a 167 ±12 Ma $^{40}Ar/^{39}Ar$ age for glaucophane from the CMS as the approximate time of metamorphism. They also suggest that metamorphism predated underthrusting of the schist to its current structural position due to a lack of the 162 Ma plutons within the CMS which invaded the upper plate rocks. This analysis is predicated on the 167 Ma cooling age and ignores the large ±12 m.y. uncertainty. In contrast, we interpret peak metamorphism and underthrusting of the CMS to post-date the 162 Ma upper plate plutonism. Relations along the southern end of the Scott River appendage indicate that ductile thrusting accompanied peak metamorphism and deformation in the CMS, and that an inverted metamorphic gradient existed across the thrust fault. U/Pb zircon and Ar/Ar hornblende data for sample 2 strongly suggest that thrusting commenced between ~160 and 155 Ma and that cooling to ~450°C along the thrust zone was attained by ~152 Ma.

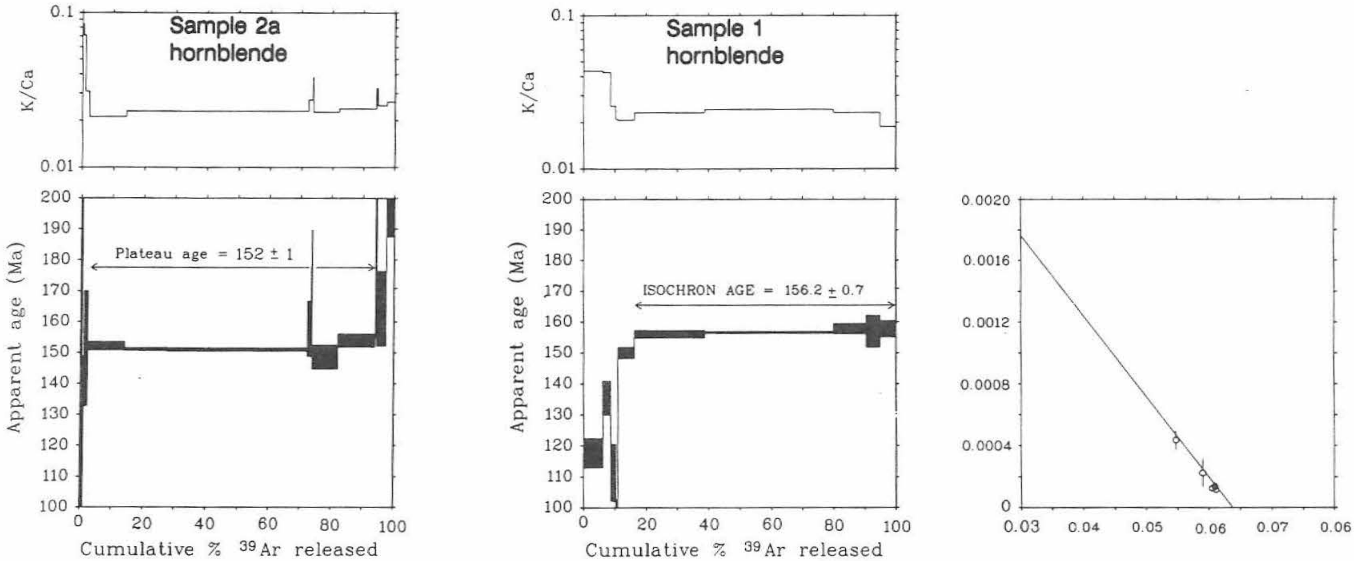


Figure 4. ^{40}Ar/^{39}Ar age spectrum and isochron plot for hornblendes from sample 1 hornblende diorite in the upper plate cut by the Condrey Mountain thrust (41° 48.8'N 121° 05.1'W), and sample 2a amphibolite along the Condrey Mountain thrust at the southern end of the Scott River appendage (41° 40.9'N 123° 05.9'W).

The cooling history of the CMS and the adjacent upper plate rocks is fairly well constrained by Ar/Ar data. As mentioned above, the thrust itself cooled to the hornblende closure temperature by ~152 Ma at the southern end of the Scott River appendage. Donato and Lanphere (1992) report an identical hornblende closure temperature from Marble Mountain terrane rocks north of the eastern end of the Klamath River appendage. The 156 Ma Ar/Ar age for the sample 1 diorite immediately above the thrust records cooling of igneous hornblende in the upper plate immediately above the thrust fault. It is likely that the dioritic intrusive body is part of the 162 Ma upper plate plutonic suite. The cooling history along the thrust and the age relations of the upper plate plutons suggest that the upper plate was warm crust inherited from the 162 Ma magmatic pulse, and that its juxtaposition with the cool, and possibly fluid rich CMS protolith led to the inverted metamorphic gradient. Prolonged cooling through lower grade conditions is recorded in the lower plate schist by K/Ar and Rb/Sr white mica cooling ages that scatter between ~150 and ~125 Ma (Lanphere and others, 1968; Helper and others, 1989).

Siskiyou Thrusting and Metamorphism

Siskiyou thrusting consisted mainly of W-directed basement rooted thrust faults and low P/T dynamothermal metamorphism within the RCT, WHT and adjacent terranes (Harper and Wright, 1984; Coleman and others, 1988; Wright and Fahan, 1988). This was an intra-arc event that was superposed over actively forming plutonic and volcanic centers (Davis and others, 1978; Wright and Fahan, 1988) leading to the low P/T metamorphic environment. Wright and Fahan (1988) have constrained the Siskiyou event to the time interval of ~169 Ma to 161 Ma. An important local constraint is that the 162±1 Ma Wooley Creek batholith and Slinkard pluton cut Siskiyou structures that are confined to the upper plate of the Condrey thrust.

Numerous workers have stated or implied that Siskiyou deformation and metamorphism was distinct from the Late Jurassic Nevadan event to the west, separated by rifting and the opening of the Josephine (ophiolite) inter-arc basin (Snoke, 1977; Saleeby and others, 1982; Harper and Wright, 1984; Coleman and others, 1988; Wright and Fahan, 1988). The probable time span of Condrey thrusting and metamorphism discussed above (~160 Ma to 155 Ma) largely coincides with the hypothetical interlude between the Siskiyou and Nevadan events.

Nevadan Thrusting and Metamorphism

The Nevadan event in the study area is represented primarily by eastward underthrusting of the JS Galice beneath the RCT along the Orleans thrust fault (Snoke, 1977; Harper, 1984; Harper and Wright, 1984; Jachens and others, 1986). Critical time constraints for Nevadan thrusting are posed by biostratigraphic data on the Galice Formation indicating deposition of Kimmeridgian flysch prior to underthrusting, and a family of plutons that cut upper and lower plates as well as the thrust itself as early as 150 Ma and possibly 152 Ma (Saleeby and others, 1982; Harper and others, in press). These relations, as well as additional age data on dikes that cut the Galice-Josephine section, indicate that Nevadan underthrusting began at ~155 and was over by 150 Ma. This, or perhaps a slightly earlier phase of underthrusting, also led to the emplacement of Galice rocks beneath the CMS near the eastern end of the Klamath River appendage (Klein, 1977; Hill, 1984, 1985).

Nevadan thrusting and metamorphism to the north of the study area occurred during a similar ~155 to 150 Ma time interval as well, but involved the overthrusting of the Josephine ophiolite across the RS Galice as well as across the arc plutonic roots of the Rogue Formation (Harper and others, 1990, in press). Deformation and low grade regional metamorphism is constrained to have continued in this region until ~135 Ma (Harper and others, in press).

Josephine Ophiolite Basin Development

Development of the Josephine ophiolite basin was active during 164 to 162 Ma based on U/Pb zircon dates on felsic members of sheeted dikes from widely spaced localities (Wyld and Wright, 1988; Harper and others, in press). Ensuing pelagic and distal volcaniclastic deposition occurred in late Callovian-Oxfordian time and was followed by Kimmeridgian flysch deposition (Harper, 1984; Pessagno and Blome, 1990). Additionally, the radiolarian data show a change from central Tethyan to southern Boreal affinities which suggests rapid northward transport during pelagic sedimentation. If this analysis proves correct, the most direct manner in which to transport the ophiolite would be for the spreading center to have been south of the Josephine massif as spreading continued.

The Josephine ophiolite and the California Coast Range ophiolite have similar igneous age constraints, pelagic-distal volcaniclastic sedimentation patterns and suprasubduction zone generation sites (Saleeby, 1981, 1983, 1992; Harper and others, 1985). This has led to the interpretation that the Josephine and Coast Range ophiolites formed in the same 1,000 km scale interarc and igneous forearc basin system along the southwest Cordilleran plate edge. Some igneous ages for the Coast Range ophiolite are as old as 170 ±1 Ma (Saleeby and others, 1984 and unpub. data). Thus spreading in the hypothetical Josephine-Coast Range ophiolitic basin system probably lasted for at least 10 m.y. with the younger domain of the system (165 to 160 m.y.) having for some reason been preferentially preserved. Below we will explore the possibility that additional remnants of the older domain of this basin system are represented in the study area by the CMS and the China Peak complex.

TECTONIC AND PALEOGEOGRAPHIC RECONSTRUCTIONS

The timing and tectonic relations of the Siskiyou and Nevadan events as well as the age of the Josephine ophiolite have been well established by a number of studies as outlined above. Since the rejection of Klein's (1977) proposed correlation between the Galice Formation and the CMS, little progress has been made on the paleogeographic history of the CMS, other than proposing that it represents a distinct unrelated terrane (Hill, 1984, 1985; Blake and others, 1985; Helper, 1986; Coleman and others, 1988). We have presented new data which constrain the protolith and metamorphic ages of the CMS as well as rocks lying directly above the CMS. In the discussion below, we will explore the implications of these new data on the Galice-CMS problem by discussing alternative tectonic-paleogeographic models. In the initial cross-section reconstructions of Snoke (1977), Saleeby and others (1982), and Harper and Wright (1984) the WHT arc became a remnant arc during the opening of the Josephine interarc basin as arc activity shifted westward to the Rogue fringing arc. The system was then telescoped and imbricated during the ensuing Nevadan orogeny. A problem with these reconstructions is that the age of Siskiyou thrusting and Josephine basin spreading significantly overlap. One solution is significant tangential tectonic transport components and basin growth in and out of the cross-section plane (Saleeby, 1981, 1992; Harper and others, 1985; Wyld and Wright, 1988). In such a kinematic regime rocks formed and deformed simultaneously in transtensive and transpressive domains may ultimately be juxtaposed with one another.

One solution for the CMS protolith problem may be developed from Donato's (1987; Fig. 11c) pre-Nevadan reconstruction. In this scenario the Middle Jurassic arc of the Klamath Mountains initiated in a broad extensional regime where basinal hemipelagic and epiclastic as well as more proximal volcaniclastic strata of the WHT lapped across an older Permo-Triassic to Early Jurassic subduction accretionary complex. Swarms of sheeted dikes locally cut into this extensional environment as early as 172 Ma, as represented by the China Peak complex, and possibly the Preston Peak mafic complex. The protolith for the CMS formed along the outer (forearc) edge of the Middle Jurassic extensional arc within a rift basin analogous to the late Tertiary Bonin forearc (Yuasa and others, 1982; Casey and Dewey, 1984). At ~169 Ma, the extensional arc was imbricated internally by west-directed thrust faulting. Thrusting was concentrated first along the magmatic axis of the arc, giving rise to the Siskiyou event sensu stricto. Thrusting then migrated westward and cool wet sediments and basement rocks of the CMS protolith were thrust beneath the hot Siskiyou metamorphic core resulting in crustal scale inverted metamorphic gradient. The Josephine ophiolite and Galice Formation were transported into the cross-section plane as Condrey thrusting progressed, and then subsequently thrust beneath the CMS in Nevadan time. In this reconstruction there are no primary relations between the Galice and the CMS, although they formed in broadly analogous depositional and tectonic settings. The CMS protolith would conceivably have had broad facies ties to the WHT, however.

Reconstructions that link the CMS protolith more closely to the Galice Formation, and the China Peak complex to the Josephine ophiolite, may find some rational basis in the similarities in the oldest ages measured on the Coast Range ophiolite and the China Peak dikes as well as the igneous ages on the CMS. Such reconstructions consider the Josephine (and Coast Range) basin system to have initiated spreading by 172 Ma with vestiges of its oldest domains actually represented by the CMS as well as the China Peak complex. In this reconstruction, the China Peak complex is distinct from and structurally beneath the RCT and thus more akin to the WKT. Spreading within the Josephine (including Condrey, China Peak and Coast Range) basin system completely coincided in time with and outlasted Siskiyou thrusting, and was located to the south of the Siskiyou deformation zone. The Andaman Sea geometry as depicted in Saleeby (1981) and Wyld and Wright (1988) appropriately accounts for all the spatial and temporal relations in this scenario, with broad time transgressive facies relations between older basinal deposits and underlying igneous crust, represented by the CMS and possibly the China Peak complex and the younger deposits and igneous crust represented by the JS Galice.

Significant tangential displacement patterns within the Siskiyou-Nevadan deformation system not only negates problems arising in strictly cross-sectional reconstructions, but are also suggested by a variety of data. Most notable are the spreading geometry deduced for the Josephine ophiolite (Harper and others, 1985), thrust kinematic relations for the Condrey Mountain window and WKT, reviewed above, regional paleobiogeographic and paleomagnetic data (Van der Voo and others, 1980; Yole and Irving, 1980; Hillhouse and Gromme, 1984; Taylor and others, 1984; Hopson and others, 1986; Blome, 1987; Pessagno and Blome, 1990), and absolute motion analysis of North America based on Apparent Polar Wander path (APW; May and Butler, 1986; May and others, 1989). Regional extension that is so well recorded in the rocks of the study area may actually have been established along the entire southwest Cordilleran plate edge as early as latest Triassic-Early Jurassic time with a localization of rifting along the forearc region (Josephine-Coast Range ophiolites) in the Middle Jurassic (Saleeby and Busby-Spera, 1992). Extensional tectonism throughout the early Mesozoic southwest Cordilleran arc may have been promoted by a combination of North America's retreat component of absolute plate motion (J1-J2 APW track calculated from May and Butler's 1986 corrected plateau data), and subduction of old, cold Panthalassan lithosphere inherited from the Pangaea regime (Saleeby and Busby-Spera, 1992). Adoption of the dextral-sense transtensional spreading model (Saleeby, 1981; Wyld and Wright, 1988) is based on the Middle Jurassic northward transport pattern that was evidently widespread in the outer Cordilleran terranes including the Josephine ophiolite as discussed in references given above. The sinistral sense spreading model of Harper and others (1985) could be applicable if, by some combination of future chronostratigraphic and paleomagnetic data, the J2 APW cusp is shown to be as old as 164 Ma, and if the Josephine domain of the basin was coupled to North America prior to Nevadan underthrusting.

An important problem posed by the tangential spreading scenario is whether substantial crustal fragments (terranes) migrated along the forearc side of the Josephine interarc basin system, or whether such fragments are limited to the Rogue arc complex and possible rifted forearc-fringing arc components of the Coast Range ophiolite. The later view was presented in Saleeby (1981) and Harper and others (1985). In our current reconstruction we adopt the former view in the light of Cordilleran-wide tectonic relations. Figure 5 shows the Josephine interarc basin system growing in the wake of the large-scale northward transport of the Insular Superterrane, a composite arc terrane that was accreted to the Pacific northwest region in Middle to Late Jurassic time after migrating from sub-equatorial latitudes (after Saleeby and Busby-Spera, 1992). Widespread diachronous and generally northward migrating Middle Jurassic thrusting and metamorphism of the Sierra Nevada-Klamath Mountains region may reflect transpressional and/or collision deformation along the inner edge of the migrating superterrane, linked to a transtensional interarc basin system that opened in its wake. This orogen-basin system may have evolved wholly above the east-dipping Cordilleran subduction zone, or alternatively, the Insular Superterrane may have traversed a major ocean basin prior to encountering the Cordilleran active margin.

In Figure 5a we consider the alternative plate kinematic regimes for Siskiyou deformation, Josephine basin spreading and Insular Superterrane migration. The first considers an oblique collision with the Superterrane impacting the Cordillera subduction zone. The Superterrane undergoes northward migration and clockwise rotation with its Euler pole located within the collision zone. This leads to northward migration of the Josephine rift system superposed along the collisional suture which is analogous to the modern Woodlark basin rift system migrating into the active Papua-New Guinea collisional belt (Schouten and Benes, in press). The second alternative considers a northward transpressive-transtensive migration pattern for the Superterrane wholly above the west-facing Cordillera subduction zone. In this scenario migration of the Superterrane is dynamically linked to spreading in the Josephine basin system which is analogous to the migration and deformation of the Burma plate linked to spreading in the Andaman Sea (Curray and others, 1979). Time-space patterns in arc igneous activity along both the Superterrane and the Sierran-Klamath magmatic arc, and Middle Jurassic deformation-metamorphic chronologies of the southwest Cordillera are discussed fuller in the context of this scenario in Saleeby and Busby-Spera (1992). In Figures 5b-d we adopt the suprasubduction zone scenario for our more detailed reconstruction which would be similar to the

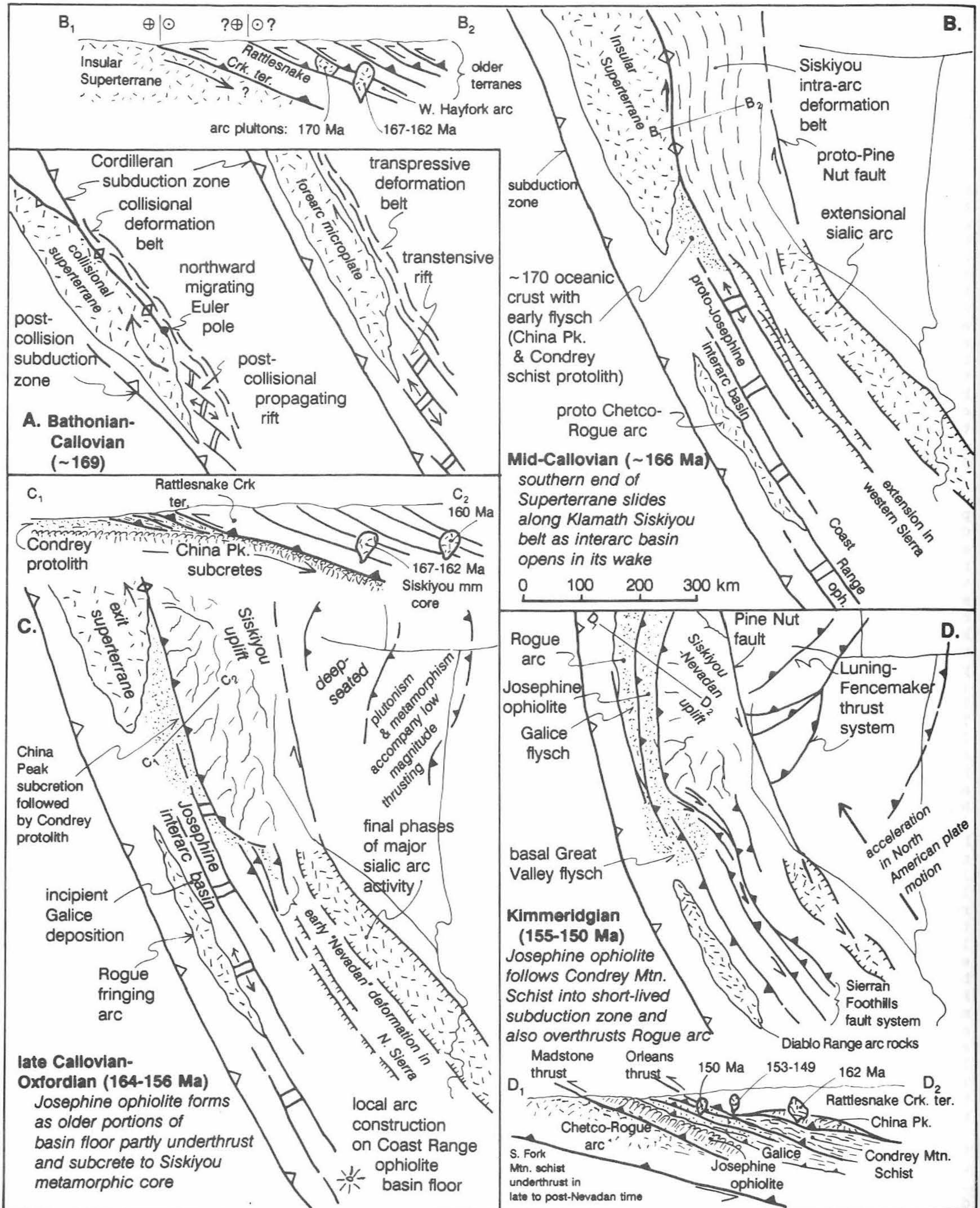


Figure 5. Reconstruction of spreading history of Josephine-Coast Range ophiolite basin system and its possible relations with Siskiyou and Nevadan deformation events, the protolith histories of the Condrey Mountain Schist and China Peak complex and the northward migration pattern of the Insular Superterrane - a large composite arc terrane that was accreted to the Pacific northwest in Middle to Late Jurassic time.

later phases of the collisional scenario as a post-collisional east-dipping subduction formed under the Superterrane.

Figure 5b depicts Siskiyou time (~166 Ma) with peak deformation having ceased in the Sierra Nevada, but affecting the Klamath Mountains region. The inset shows a cross-section view of the Siskiyou intra-arc thrust belt after Wright and Fahan (1988). Bathonian to early Callovian interarc basin crust has grown in the wake of the Superterrane and includes the oldest fragments of the Coast Range ophiolite as well as the China Peak complex and the CMS protolith. Transpressively displaced and transtensively rifted screens of RCT rocks could have been derived from as far as 500 km to the south of the Klamath Mountains, considering that Rattlesnake Creek-like assemblages are widespread along the western Sierra Nevada metamorphic belt (Saleeby, 1990). In this view the Great Valley basement is considered a major track of the Middle Jurassic interarc basin floor which formed by rifting off the frontal edge of the western Sierra belt (cf. Saleeby, 1981, 1992).

In Figures 5b and c the Rogue arc complex is shown developing on a large rifted fragment of RCT-like rocks (Yule and Saleeby, 1991; Yule and others, 1992). Whether this rifted fragment represented the outer limit of the interarc basin, versus a large screen within the basin, is uncertain. There are additional fragments of Middle Jurassic suprasubduction zone ophiolite and outliers of Galice Formation in the westernmost Oregon Klamaths and Coast Ranges west of the Rogue arc complex (Fig. 1); these may be fragments of the Coast Range ophiolite and western Klamath terrane that were dispersed northward by dextral faulting significantly later, however (Saleeby, 1992). The Rogue fringing arc is shown in Figure 5b and c to be coupled to and moving with the Josephine domain of the interarc basin.

Figure 5c shows late Callovian-Oxfordian time with generation of the largest tract of presently preserved interarc basin crust - the Josephine and much of the Coast Range ophiolites. Unlike the polygenetic basement complex beneath the Rogue fringing arc, apparent fringing arc volcanic rocks of the Coast Ranges were erupted on rifted forearc and/or juvenile interarc basin crust. The Figure 5c geometry poses the possibility that interarc basin crust of the China Peak complex may have begun its subcretion beneath the RCT in late or immediately post-Siskiyou time as the forerunning Superterrane cleared the Klamath region and oblique subduction of interarc basin floor commenced. As shown in the cross-sectional inset, the next major subduction thrust sheet to follow was the CMS protolith during the Siskiyou-Nevadan interlude or in early Nevadan time.

Figure 5d depicts the Nevadan orogeny in Kimmeridgian time. By ~155 Ma the CMS had completed its subcretion to the hanging wall of the subduction zone beneath the Siskiyou thrust belt. The Josephine domain of the basin floor followed with a NE trajectory into the subduction zone. As it approached the subduction zone it was covered with the Galice flysch derived from the Siskiyou uplift. The flysch lapped across the submarine pyroclastic aprons and lava shields of the coupled Rogue fringing arc as well. As the Josephine basin floor underwent northeast descent into the subduction zone the North American plate underwent a rapid NW-directed change in its absolute motion (J2 APW cusp of May and Butler, 1986). Subduction ceased with the subrection of the JS Galice and superposed cross-structures of the CMS and JS Galice formed while the outer fringes of the Josephine basin floor detached and were obducted to the NW over the Chetco roots of the Rogue fringing arc (Harper and others, 1990, in press). The cross-sectional inset depicts this structural stacking arrangement. Widespread sinistral-sense diking and transpressive-transtensive deformation patterns of the Sierra Nevada region record a similar kinematic pattern for precisely the same time interval (Saleeby and Busby-Spera, 1992; Wolf and Saleeby, 1992). Thus the entire western Sierra-Klamath orogen underwent a rapid sinistral-sense wrench deformation at Nevadan time that was opposite to the dextral spreading and terrane migration pattern that had preceded Nevadan time. The backarc region also underwent a pronounced sinistral-sense deformation during Late Jurassic time in the form of SE-directed thrust sheets of the Luning-Fencemaker system and the bounding Pine Nut sinistral fault (Oldow and others, 1984).

A final point that is pertinent to the Galice-CMS problem concerns Early Cretaceous high P/T metamorphic rocks of the Franciscan complex. Most notable is the South Fork Mountain schist which partly bounds the WKT along the South Fork fault, and which has been compared by some workers to the lower unit of the CMS (Brown and Blake, 1987). Meager protolith age constraints and protolith features for the South Fork Mountain schist permit its protolith to have been remnants of the Middle Jurassic interarc basin system, but which survived Nevadan deformation, and was the first thrust wedge to descend during Franciscan subduction. The younger mica cooling ages that are widespread in the study area, and particularly in the lower unit of the CMS (Helper and others, 1989) probably records this phase of subduction tectonics. An important problem posed by the CMS is whether the lower unit merely records Early Cretaceous underthrusting and uplift in its cooling ages, or if it actually represents a South Fork Mountain schist inlier that was subcreted beneath the entire Siskiyou-Nevadan thrust stack in Early Cretaceous time. We prefer the former interpretation in our reconstruction. A critical test to verify this interpretation is better documentation the CMS pelite-rich schist unit of the easternmost Klamath River appendage (Figure 2) which is cut by Nevadan structures.

CONCLUSIONS

Isotopic and biostratigraphic age data prohibit a correlation between the Galice Formation and CMS in spite of lithologic similarities and structural stacking arrangement that suggests such a correlation. Nevertheless, these same data sets when viewed in a regional context with an appreciation for the dynamic relations and typical rates of interarc rifting, basin growth, sedimentation, and basin closure by subduction can be construed to suggest that there were strong tectonic ties and perhaps time-transgressive facies relations between the two assemblages. The alternative interpretation that they are totally unrelated allochthonous terranes, while possible, does not challenge the imagination into a process-oriented analysis of their tectonic histories.

In the simplest case, the CMS could have been derived from a stratigraphic sequence that was very similar to the Galice Formation, but 10 to 15 m.y. older, and it could have sat conformably on the same interarc basin floor as the Galice. The basin floor probably formed over a 10 to 15 m.y. time interval with CMS sedimentation occurring on older domains and Galice sedimentation on a younger (Josephine ophiolite) domain. The interarc basin floor was progressively subducted northeastward beneath older Klamath terranes over a time period perhaps as long as 10 m.y. and possibly overlapping in time with the sea floor spreading growth of the younger domains of the basin. In this view, the CMS was subcreted early in the subduction history followed by partial subcretion of the younger Galice. An additional fragment of the interarc basin floor may have been subcreted prior to the CMS as the China Peak complex. Such a structural arrangement of China Peak complex, CMS and finally Galice-Josephine ophiolite at the base represents a basement-level accretionary prism-like structure. More complex, primary geometries may be envisaged whereby the CMS protolith and the China Peak complex represent parts of the outer rifted fringes of the pre-Josephine/Galice Jurassic arc, and then a similar imbrication history as outlined above followed. Resolution between these alternatives may be found by a greater protolith characterization of the CMS and China Peak complex, and comparative studies with the Galice and its substrates and the Middle Jurassic arc rocks of the WHT.

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